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Dating Stonehenge

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5.1 Introduction

English Heritage recently funded a project to write up and publish the twentieth-century excavations at Stonehenge (Cleal *et al.* 1995). To determine the site's chronology the radiocarbon dates were assessed for reliability on scientific and archaeological grounds. Sixteen samples had been measured between 1950 and 1994, although the rejection of six of them left only ten which we considered reliable. Forty-eight new radiocarbon determinations were commissioned in 1994 and 1995, although four of them were also rejected as unreliable on archaeological grounds. Consequently the analyses presented here include only the remaining 54 measurements, 44 from the new programme and 10 from previous research. Details of the samples are provided in Table 5.1 on page 31.

The intention of this paper is to provide an account of the processes of archaeological and mathematical reasoning which led to the published model of the site's chronology. Details of this model and the dating programme have been fully published elsewhere (Allen & Bayliss 1995, `http://www.eng-h.gov.uk/stoneh`). In particular we report some of the models which were produced as part of the analytical process and, although not regarded as the most realistic by the authors, still provided useful information. The inclusion in the analysis of two further measurements taken in the last few months, also leads to slight changes in the preferred model.

In addition to providing an absolute chronology for the monument, the dating programme was designed to address specific questions—to elucidate the sequence of major events and sub-phases where there is no recorded stratigraphic information, to assign specific features or groups of features to a phase by radiocarbon dating, and to estimate the duration of the phases. To achieve these objectives, we constructed a series of mathematical models of the chronology of the site which incorporate both the radiocarbon measurements and other, purely archaeological, information such as stratigraphy.

These models include our archaeological interpretations of the relationships between the radiocarbon samples, their contexts, and the activities of prehistoric people which we are attempting to date. Potentially there are considerable dangers in this, since these relationships are complex (Reece 1994). However we can use the models as analytical tools to test whether certain interpretations are consistent with the radiocarbon evidence. A number of different models are possible for the site. Although these will certainly change when new evidence comes to light, such modelling does give a more accurate view of the chronology of the monument than that provided simply by calibrating the radiocarbon measurements in isolation.

The first stage in our analysis was to relate the results to the calendar timescale by calibration. This was done by the usual probability method (Dehling & van der Plicht 1993; Stuiver & Reimer 1993; van der Plicht 1993) using data from Pearson *et al.* (1993, 1986); Pearson & Stuiver (1986); Stuiver & Pearson (1986), and Kromer & Becker (1993). Implicit in this method of calibration is the assumption that we have no other information about the date of the sample. To incorporate the information from site stratigraphy and archaeological interpretation we used methods based on Gibbs sampling techniques (Buck *et al.* 1992; Gelfand & Smith 1990).

The methods have been applied using the program OxCal (v2.17) (Bronk Ramsey 1995, `http://sable.ox.ac.uk/rlaha`), which was written specifically for this sort of analysis and is based largely on the original mathematical work of Buck *et al.* (1994a, 1991, 1994b, 1992). In addition to Gibbs sampling, statistical tests are included which check if the model is consistent with the dating evidence. These tests, *indices of agreement*, were devised specifically for the program, the threshold for acceptance being similar to the 5% χ^2 test. A test fails if the Gibbs sampler is forced to choose dates from very low parts of a probability distribution.

In the diagrams which follow (Figs. 5.2, 5.3, 5.6, 5.7, and 5.8) the constrained probability distributions, calculated using the stratigraphic information and archaeological interpretations in addition to the radiocarbon results, are shown in solid black; the original unconstrained distributions are shown in outline. This enables the reader to judge the effect of the mathematical modelling. All ranges derived from these constrained distributions are cited *in italics*, to distinguish them from simple calibrated date ranges.

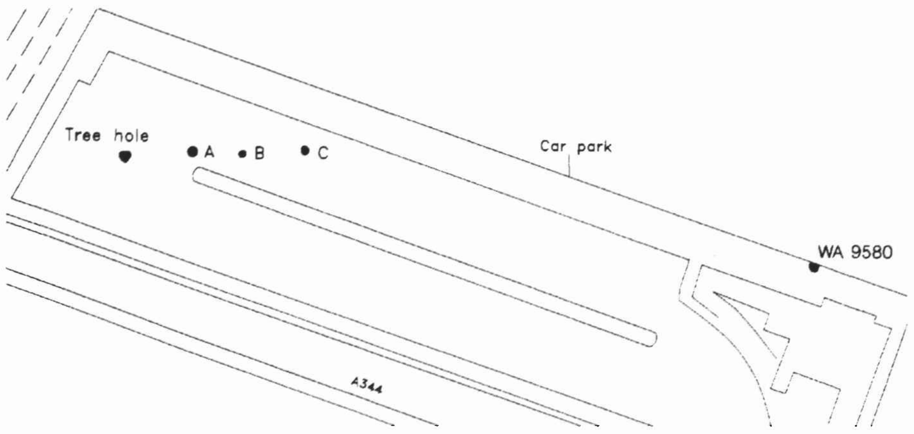


Figure 5.1: Location of mesolithic features under the car park.

5.2 Mesolithic activity

The earliest activity so far identified at Stonehenge is a series of pits beneath the present day car park (Allen & Bayliss 1995, pp. 43–7; Fig. 5.1). They have produced five radiocarbon dates from pine charcoal, all of mesolithic age (Table 5.1). The function and significance of these features is obscure, although it is possible that they held upright posts. If the five dates are assumed to be randomly selected from a uniformly deposited phase, the span of dated events is estimated to be between *300 and 1600 years*, with the events occurring between *8500–7650 cal* BC and *7500–6700 cal* BC (Fig. 5.2). This assumption weights a short phase more strongly, and, given the small number of results, does not produce useful estimates for the start and end of the phase. However it does indicate the longevity of the mesolithic activity.

5.3 Phase 1

This consists of the construction and initial use of the first monument, a segmented ditch with a bank and counterscarp bank, and the Aubrey holes as a ring of posts (Cleal *et al.* 1995, pp. 63–114; Fig. 5.4a). The only material recovered for dating which could be identified in the archive came from the base of the ditch. The potential samples included over 100 antlers and a number of animal bones. All of these were placed on the base of the ditch before any primary silt had accumulated.

The antlers have been modified into tools, both picks and rakes, with many displaying clear signs of wear (Sergeantson 1995, pp. 414–28). For these reasons it seems likely that they were used for the digging of the main ditch and then immediately deposited on its base. Since antler tools cannot be kept for a substantial time before use because they become brittle, the date of the antlers should be a good estimate of the date of the ditch digging.

Even so we did not choose to take a weighted mean of the results before calibration (Ward & Wilson 1978). This is because, although the material cannot be of widely differing ages, we cannot be absolutely sure that it is all of exactly the same age. The antlers could certainly have grown in several different seasons (see Bayliss *et al.* 1997 forthcoming for further discussion of this point).

Instead, if all the material from the base of the ditch beneath the primary silt is assumed to be randomly selected from a uniformly deposited phase, the end of this phase can be taken as an estimate of the date of the digging of the ditch. The advantage of the assumption of a uniformly deposited phase is that we can then estimate the end of that phase, not just the last dated event (which will be somewhat earlier). In fact because this estimate is so well constrained (see below) the estimates provided by the two methodologies are very similar. We know that the primary silt starts to form almost as soon as a ditch is dug (Bell *et al.* 1996), and so the last of this material must have been collected very soon after the ditch was completed.

The four dated animal bone deposits from ditch terminals were significantly earlier than the antlers. Indeed, if the results are modelled to include the constraint that the structured deposits are later than the digging of the ditch, the model is statistically significantly inconsistent ($A = 30.2\%$; Fig. 5.3), even though they must have been placed in the ditch after it was dug! The samples date to when the animal died however, not to when the bones were put on the base of the ditch, so this can be explained by the curation of the material for some time before it was deposited. Analysis of the information currently available suggests that the period of curation was for between 70 and 420 years (95% confidence).

Since there was no material suitable for dating from the primary fill or the activity on top of this, the date of the digging of the ditch can only be constrained by material from the secondary fills. These secondary fills certainly accumulated after the silting beneath them, but the crucial question is whether the material dated from these layers is residual.

To minimise the problem we chose to submit a relatively large number of samples throughout the profile. It was hoped at least some of these would not be

Context	Material	Laboratory Reference	Radiocarbon Age (BP)	Calibrated date range (95% confidence)
Mesolithic				
Postpit WA9580	*Pinus* charcoal	OxA-4919	8520±80	7700–7420 cal BC
Postpit WA9580	*Pinus* charcoal	OxA-4920	8400±100	7580–7090 cal BC
Postpit WA9580	*Pinus* charcoal	GU-5109	8880±120	8090–7580 cal BC
Postpit A	*Pinus* charcoal	HAR-455	9130±180	8820–7730 cal BC
Postpit B	*Pinus* charcoal	HAR-456	8090±140	7480–6590 cal BC
Pre-phase 1				
Sarsen Circle	Animal bone	OxA-4902	5350±80	4360–3990 cal BC
Phase 1				
Ditch	Antler	UB-3787	4375±19	3085–2920 cal BC
Ditch	Antler	UB-3788	4381±18	3095–2920 cal BC
Ditch	Antler	UB-3789	4330±18	3030–2910 cal BC
Ditch	Antler	UB-3790	4367±18	3040–2915 cal BC
Ditch	Antler	UB-3792	4365±18	3040–2915 cal BC
Ditch	Antler	UB-3793	4393±18	3095–2920 cal BC
Ditch	Antler	UB-3794	4432±22	3305–2925 cal BC
Ditch	Antler	BM-1583	4410±60	3340–2910 cal BC
Ditch	Antler	BM-1617	4390±60	3330–2910 cal BC
Ditch	Animal bone	OxA-4833	4550±60	3500–3040 cal BC
Ditch	Animal bone	OxA-4834	4460±45	3350–2920 cal BC
Ditch	Animal bone	OxA-4835	4455±40	3340–2920 cal BC
Ditch	Animal bone	OxA-4842	4520±100	3510–2920 cal BC
Phase 1/2				
Aubrey Hole 32	Charcoal	C-602	3798±275	3020–1520 cal BC
Phase 2				
Ditch	Animal bone	OxA-4841	4295±60	3040–2700 cal BC
Ditch	Animal bone	OxA-4843	4315±60	3100–2700 cal BC
Ditch	Animal bone	OxA-4880	3875±55	2560–2140 cal BC
Ditch	Animal bone	OxA-4881	4300±60	3080–2700 cal BC
Ditch	Animal bone	OxA-4882	4270±65	3040–2660 cal BC
Ditch	Bone chisel	OxA-4883	4300±70	3100–2700 cal BC
Ditch	Antler	OxA-4904	4365±55	3300–2900 cal BC
Ditch	Antler	UB-3791	4397±18	3095–2920 cal BC
Ditch	Animal bone (articulated)	OxA-5981	4220±35	2920–2660 cal BC
Ditch	Animal bone (articulated)	OxA-5982	4405±30	3300–2920 cal BC
Phase 3				
Sarsen Circle	Antler	UB-3821	4023±21	2655–2485 cal BC
Sarsen Trilithon	Antler	OxA-4839	3860±40	2470–2200 cal BC
Sarsen Trilithon	Antler	OxA-4840	3985±45	2850–2400 cal BC
Sarsen Trilithon	Antler	BM-46	3670±150	2480–1680 cal BC
Bluestone Circle	Animal bone	OxA-4878	3740±40	2290–2030 cal BC
Bluestone Circle	Antler	OxA-4900	3865±50	2480–2140 cal BC
Bluestone Horseshoe	Antler	OxA-4877	3695±55	2280–1940 cal BC
Stonehole E	Antler	OxA-4837	3995±60	2860–2350 cal BC
Stonehole E	Antler	OxA-4838	3885±40	2490–2200 cal BC
Z Hole 29	Antler	OxA-4836	3540±45	2030–1740 cal BC
Y Hole 30	Antler	UB-3822	3341±22	1735–1530 cal BC
Y Hole 30	Antler	UB-3823	3300±19	1675–1520 cal BC
Y Hole 30	Antler	UB-3824	3449±24	1880–1690 cal BC
'Beaker' burial	Human bone	BM-1582		
'Beaker' burial	Human bone	OxA-4886		
'Beaker' burial	Human bone	OxA-5044	3817±27†	2460–2140 cal BC
'Beaker' burial	Human bone	OxA-5045		
'Beaker' burial	Human bone	OxA-5046		
Avenue				
Stonehenge terminal	Antler	OxA-4884	3935±50	2580–2300 cal BC
Stonehenge terminal	Antler	BM-1164	3678±68	2290–1890 cal BC
Nr Avon terminal	Animal bone	OxA-4905	3865±40	2470–2200 cal BC
N side of A344	Antler	HAR-2013	3720±70	2350–1930 cal BC
Post-monument				
Palisade Ditch	Human bone	UB-3820	2468±27	775–410 cal BC
Sarsen Circle	Bone point	OxA-4885	2840±60	1260–840 cal BC

Table 5.1: Summary of reliable radiocarbon dates from Stonehenge. †weighted mean of 3960±60BP, 3785±70BP, 3825±60BP, 3775±55BP, and 3715±70BP.

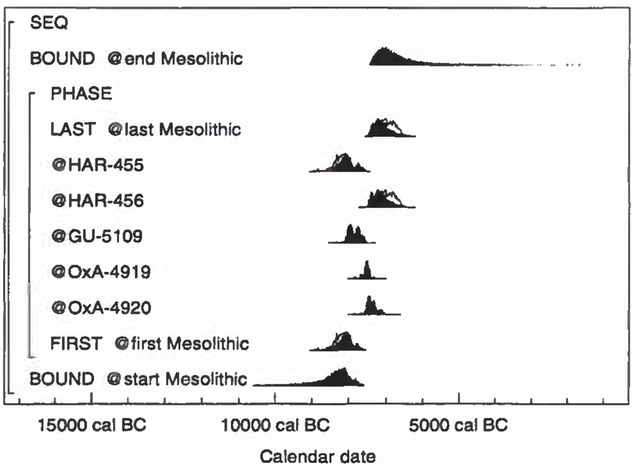


Figure 5.2: Radiocarbon dates from the mesolithic features.

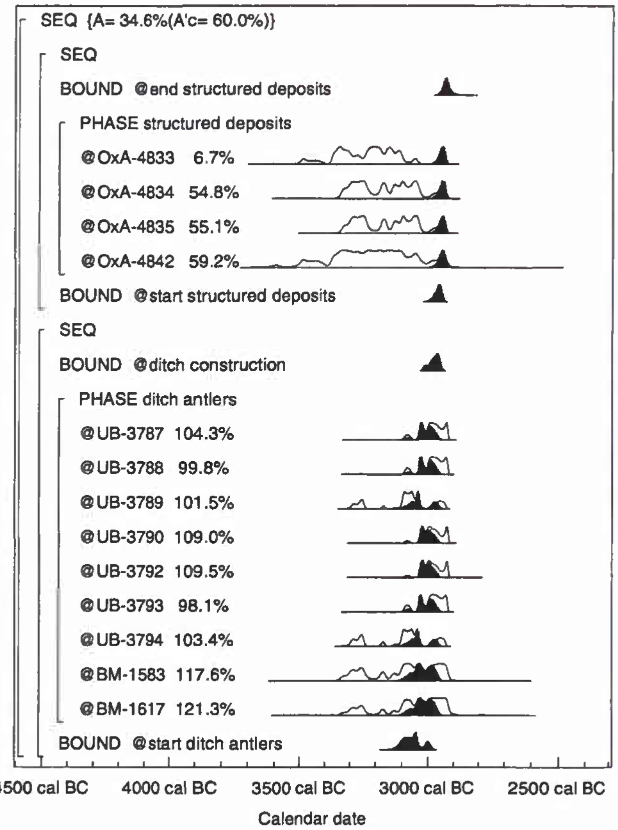


Figure 5.3: Model of the dating of phase 1, assuming that the structured deposits are later than the ditch in which they were deposited.

residual, and so the latest of them might provide a reliable estimate for how long the ditch took to silt up. Bone was selected in preference to antler because there are only 37 fragments of bone from primary silts in comparison with several hundred antlers and so bone samples should have less chance of being residual. All items were unabraded and relatively large. Unfortunately the provenance of several of these samples was shown to be unreliable when additional archival material became available on the death of Professor Atkinson in October 1994 (Allen & Bayliss 1995, pp. 520–1). The results from these samples have been excluded from all analyses.

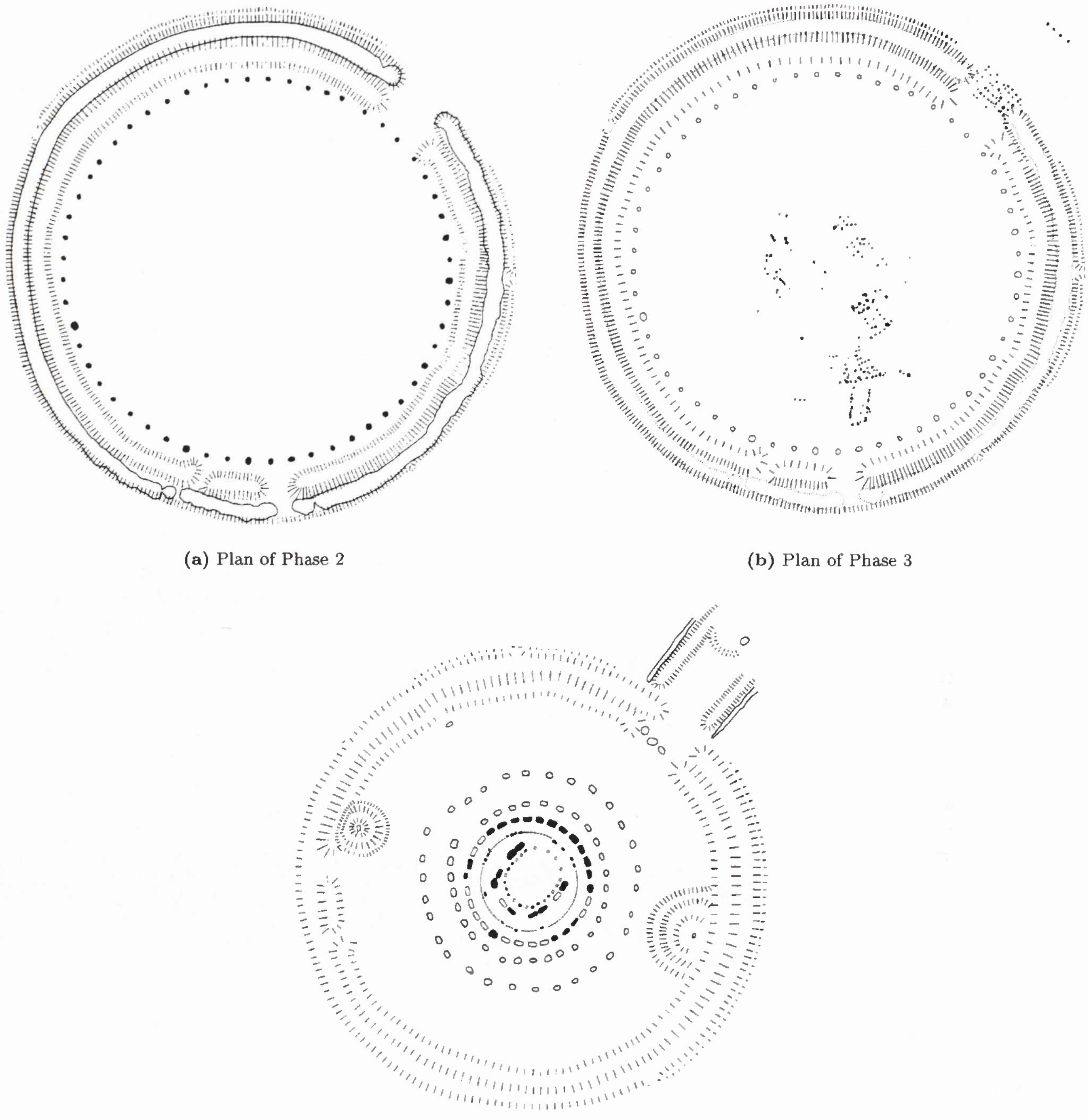
This experience left us with lingering doubts over the contextual integrity and taphonomy of the dated material from phase 2. For this reason two further samples were dated in October 1995, both from partially articulated skeletons (Fig. 5.5). The rationale behind these submissions is that, at deposition, the bones must have had at least the tendons attached or they would not have been recovered articulated. The articulation also argues against residuality or post-depositional disturbance. Full details of these measurements are presented in Table 5.2.[1]

These two samples are demonstrably not residual, so the constraint that they must be later than the material used to estimate the date of the ditch construction can be included safely in a revised model (A = 104.5%; Fig. 5.6). This produces a new estimate for the date of the digging of the ditch of *cal* BC *3015–2935 (95% confidence).*

Because of the problems encountered over the provenance of the first series of samples from phase 2, we are unwilling to use the other measurements from the secondary silts to constrain this estimate, however it should be noted that if this is done the model is still statistically consistent (A = 137.0%; Fig. 5.7). It must be stressed however that we regard the archaeological evidence on which this model is based to be sufficiently suspect for the calculated distribution to be regarded as unreliable, at least until further evidence suggests the contrary. For this reason the model shown in Figure 5.6 is preferred.

5.4 Phase 2

During phase 2 elaborate timber settings were built in the centre and across the eastern entrance of the monument (Cleal *et al.* 1995, pp. 115–65; Fig. 5.4b). The ditch silted up naturally, although there were some episodes of backfilling and small cut features within the secondary fill. Towards the end of the phase cremation burials were deposited in the Aubrey holes, ditch, and around the periphery of the monument.



(a) Plan of Phase 2

(b) Plan of Phase 3

(c) Plan of Phase 4

Figure 5.4: Phase plans of the development of Stonehenge.

Phase	General location	Cutting no	Material	Context no	Lab ref	$\delta^{13}C$ (‰)	^{14}C age (BP)	Calibrated date range (2σ) cal BC
2	Ditch, secondary	C20	piglet	AB49, AB50	OxA-5981	−21.2	4220±35	2920–2660
2	Ditch, secondary	C42	cattle vertebrae	S54: 862, 834, 854	OxA-5982	−23.0	4405±30	3300–2920

Table 5.2: Details of two samples measured in October 1995.

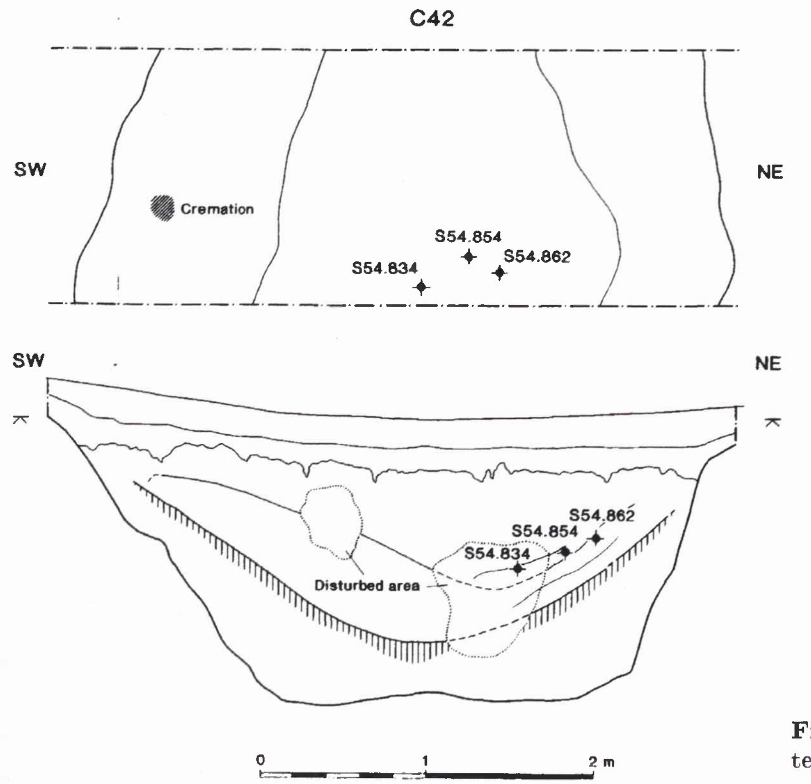


Figure 5.5: Location of articulated vertebrae in the secondary silting of the ditch.

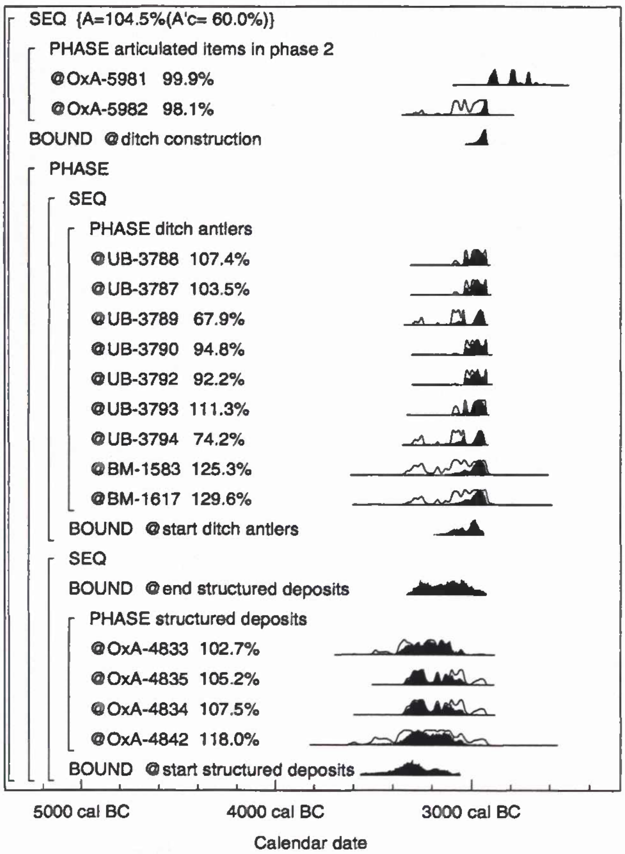


Figure 5.6: The dating of phase 1.

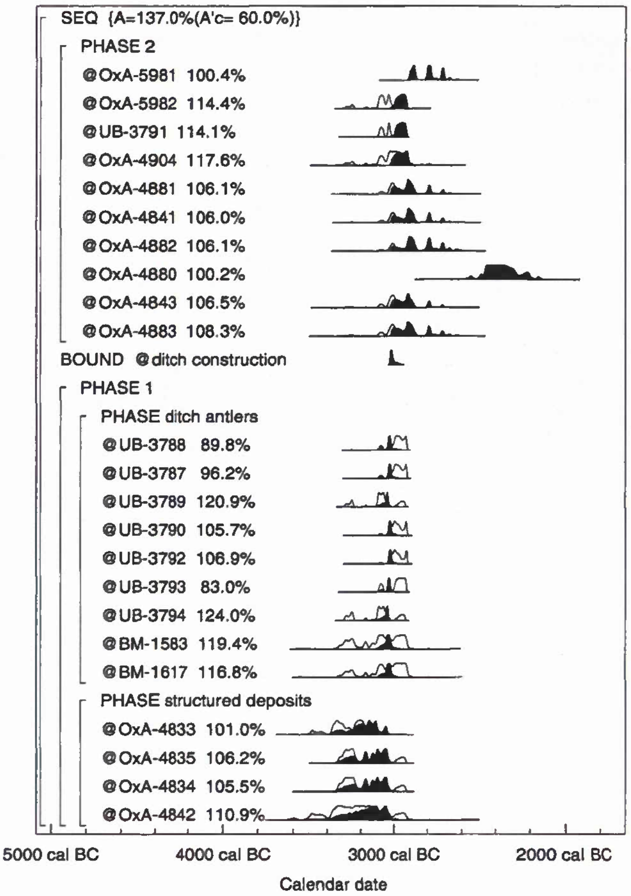


Figure 5.7: The dating of phases 1 and 2.

The only material which was available for dating from phase 2 came from the secondary silts of the main ditch. These samples have been discussed above. A number of bone pins which had accompanied cremation deposits in the Aubrey holes were also submitted for dating, but all proved to contain too little collagen for successful analysis.

In addition to their archaeological relationships with the digging of the ditch, the analysis of the samples from the secondary silts can be constrained by an inhumation burial which was cut through them (Evans 1984). This happened within phase 3, as shown by a fragment of bluestone which was discovered in the grave fill. The burial therefore provides a *terminus ante quem* for the infilling of the ditch and demonstrates that at least some of phase 3 post-dates phase 2, although there is no reason to believe that the two phases do not overlap.

No attempt has been made to model the rate of ditch infill, since it has been demonstrated empirically that this is not uniform (Bell *et al.* 1996; Crabtree 1990). Consequently the best estimates for the start and end of the infilling of the ditch rely on the constrained estimates for the first and last dated event from the secondary fill. These are *cal* BC *3300–3230 (9% confidence)* or *cal* BC *3110–2950 (86% confidence)* and *cal* BC *2460–2210 (95% confidence)* respectively. The difference between the distributions can be calculated suggesting that the infilling of the ditch took between *460 and 740 years (95% confidence).*

The first dated event in phase 2 has been calculated using the two measurements on articulated material only. This is because of the concerns over the possibility of residual material discussed above. The estimate is relatively imprecise for this reason and should be treated with caution. Nonetheless, if the distribution is compared with that for the construction of the ditch, it can be estimated that phase 1 was fairly short, lasting for between *0 and 75 years (95% confidence).*

5.5 The stone monument

This phase saw the construction of the familiar stone settings, which seem to echo the earlier timber structures (Fig. 5.4c). The overall plan of the monument remained the same through time, but there was a complex, and poorly understood, sequence of modifications to the layout of the stones.

Unfortunately very little material survived for dating from this phase of activity. The majority of the items dated were pieces of bone or antler from the primary fills of stone-holes. As there is no functional relationship between these items and the context in which they were found, the measurements can only provide a series of *termini post quem* for the settings. Thus the last dated event in each dated setting was calculated on the principal that a context dates to the latest material within it. The limited stratigraphic sequence which is available for the centre of the monument was included in the model, with each setting treated as a single event. For example Z holes 2 and 7 cut through the ramps for stoneholes 2 and 7 of the sarsen circle respectively, but the model includes the constraint that all the Z holes are later than all the stoneholes of the sarsen circle. This extended interpretation is supported by the clearly unitary layout of the different elements of the monument.

The results of the analysis of phase 3 are presented in Table 5.3 and Figure 5.8. It should be noted that some estimates are more reliable than others. This is because some rely on a single measurement. These are obviously less secure than an estimate which relies on three! So, although we may be 95% confident that the last dated event in Z hole 29 is *cal* BC *2030–1750*, we recognise that, as only one item has been dated and this could be residual, the estimate may be unreliable and our confidence misplaced.

The taphonomy of material from the Y and Z holes is different from that from the other stone-holes. These samples came from what appeared to be deliberately placed antler deposits on the bottom of the holes (Fig. 5.10). The antlers were conspicuously different from those on the base of the ditch because they showed no evidence of modification into tools. Indeed analysis of the three results from antler stacked on the base of Y hole 30 suggests that all the antlers were not of the same date (Ward & Wilson 1978, T'=24.1, 5%=6.0), and that at least some of the material had been curated for a substantial period of time before deposition. In the light of this the single result from Z hole 29 appears likely to be on curated material, since on grounds of spatial organisation, it is considered likely that the two settings are contemporary and part of the same planned modification (Cleal *et al.* 1995, pp. 264–5).

Comparison of the probability distributions calculated to estimate the first dated event from the stone monument and the last dated event from the infill of the ditch suggest that it is very likely (over 95% confidence) that the two phases overlap. It is not possible to ascertain the order of the events of construction of the different stone elements with any degree of confidence although it does appear that the sarsen settings predate the bluestone settings, and the bluestone settings predate the Y and Z holes (again over 95% confidence).

5.6 The Avenue

The avenue consists of parallel ditches which extend for nearly 2.8km from the monument to the river Avon (Fig. 5.11). The specific aim of dating this feature was to determine whether the two main sections (that near the monument and that beyond the elbow at Stone-

Event	Calculated date ranges
Sarsen Circle	2850–2830 cal BC (1% confidence) or 2660–2640 cal BC (2% confidence) or 2620–2480 cal BC (92% confidence)
Stonehole E	2480–2270 cal BC (92% confidence) or 2240–2200 cal BC (3% confidence)
Beaker-age burial	2400–2380 cal BC (2% confidence) or 2360–2190 cal BC (90% confidence) or 2170–2140 cal BC (3% confidence)
Sarsen Trilithons	2440–2100 cal BC (95% confidence)
Bluestone Circle	2280–2030 cal BC (95% confidence)
Z Hole	2030–1750 cal BC (95% confidence)
Y Hole	1640–1520 cal BC (95% confidence)

Table 5.3: Estimated dates for the stone settings and related activity in Phase 3 at Stonehenge.

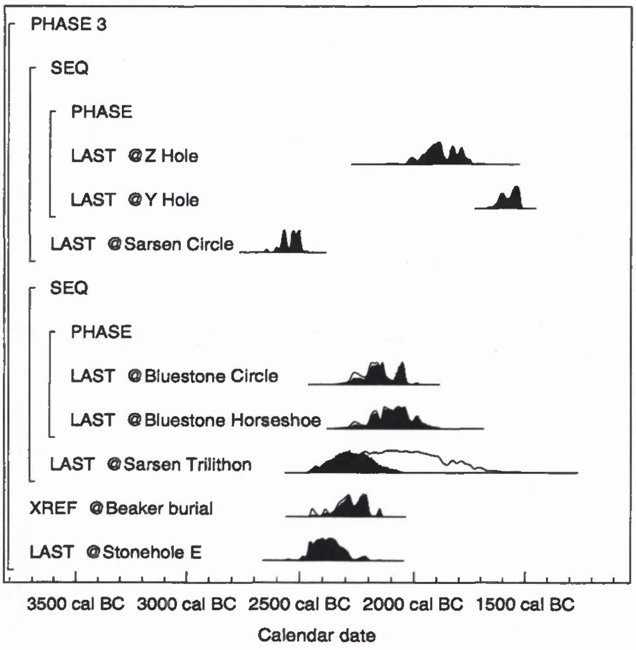


Figure 5.8: The dating of phase 3.

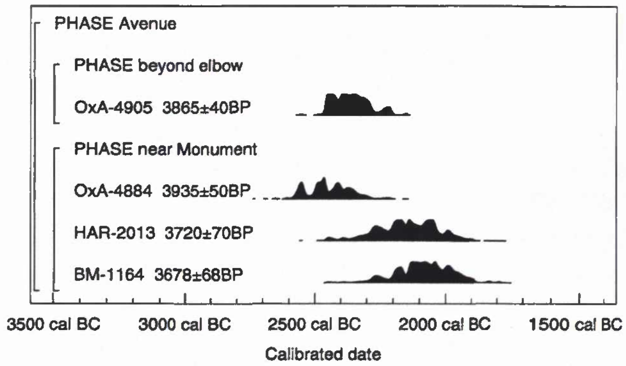


Figure 5.9: The dating of the Avenue.

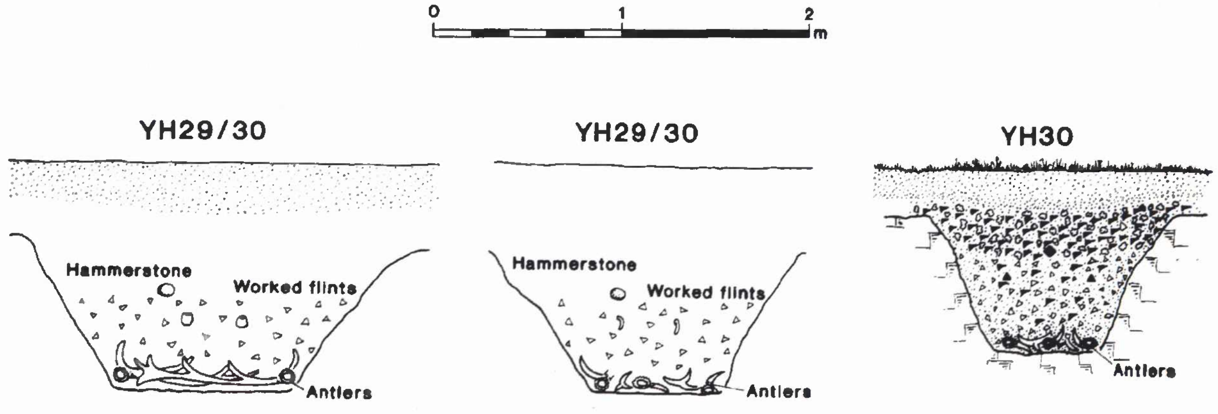


Figure 5.10: Sections through Y Hole 30.

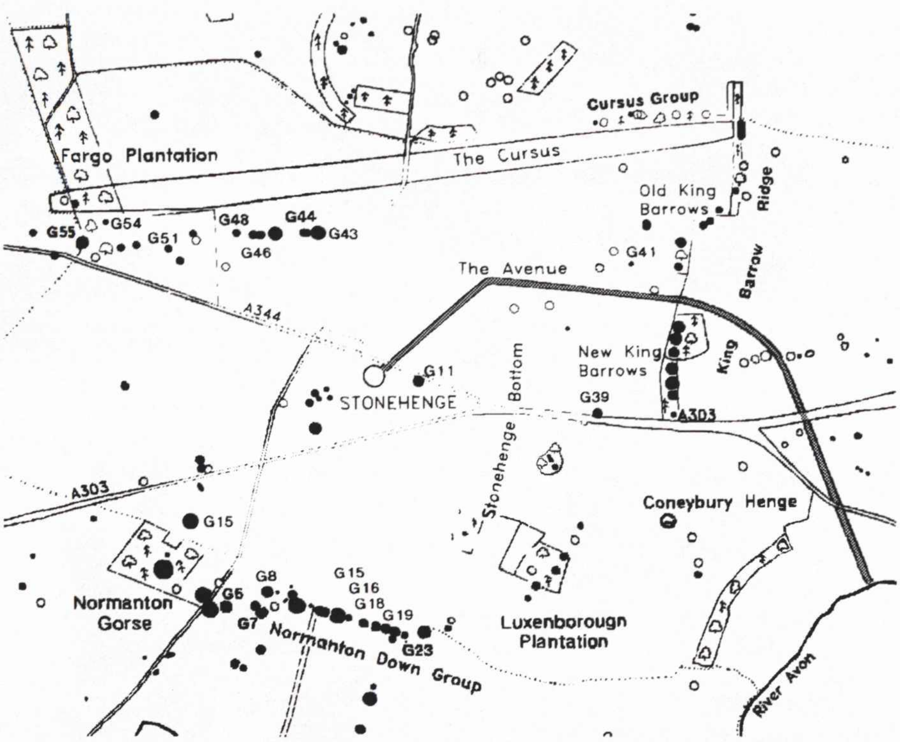


Figure 5.11: Plan of Stonehenge and the Avenue, within the modern landscape.

henge Bottom) were contemporaneous, or if not, to determine the order of construction.

Unfortunately only four reliable results are available from the Avenue. The almost complete lack of datable material recovered from excavation meant that only two further samples could be submitted (Table 5.1). These do not enable us to resolve the questions posed above, although analysis of the results (Fig. 5.9) does suggest that the construction may have extended over several centuries, as the dated events cover a period of *190 to 640 years (95% confidence).*

5.7 Later use

From the later Bronze Age, use of the site seems to have been essentially superficial (Gardiner 1995). Two results date this period of activity. One is from an Iron Age burial which was cut into the terminal of the palisade ditch (UB-3820; 2468±27BP; *780–410 cal* BC). As the palisade trench is considered to be late Neolithic on archaeological grounds (Walker & Montague 1995), this *terminus ante quem* is not very useful, although it does demonstrate activity around the monument at a previously unsuspected period. The second date is from an unusual bone point (Cleal *et al.* 1995, fig. 227), which was dated purely for its intrinsic interest (OxA-4885; 2840±60BP; *1260–840 cal* BC).

5.8 Conclusions

The dating programme discussed above has undoubtedly shed much new light on the chronology and development of the monument. This paper has discussed the creation of an analytical and interpretative model of the site's chronology. This is by no means definitive and will change, as further data is gathered and as future researchers examine our evidence with different questions in mind.

Although we have made some progress in our understanding of the dating of Stonehenge, fundamental problems remain unsolved. The relative dating of different parts of the Avenue and how this fits into the sequence in the centre of the stone monument has been mentioned, but the banks, the timber settings from phase 2, the palisade ditch, the north and south barrows, and many of the stone settings and single stones remain completely undated. All the stone settings are dated by a woefully small number of samples, and the single determination from the Aubrey holes (C-602; 3798±275BP), although ground-breaking when it was measured in the early 1950s, is now so imprecise as to be unhelpful.

These questions must await the initiation of new research into the monument. At present the samples to address them simply do not exist in the excavated archive. However it is hoped that the future research directions outlined in Wainwright *et al.* (1995), will enable at least some of them to be tackled within the next few years.

Notes

1. A sample of known-age wood was measured in wheel 574 along with OxA-5981 and OxA-5982. This was a sample of bristlecone pine (P-0183), dated by dendrochronology to AD 480–490. It produced a result of 1530±50 BP (δ^{13}C: −17.6‰), which compares to the measurement on the calibration curve used in

this analysis of 1565±13 BP (AD 480–500; Stuiver & Pearson 1986; see Allen & Bayliss 1995 for further details of the quality assurance measures adopted for the Stonehenge dating programme).

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